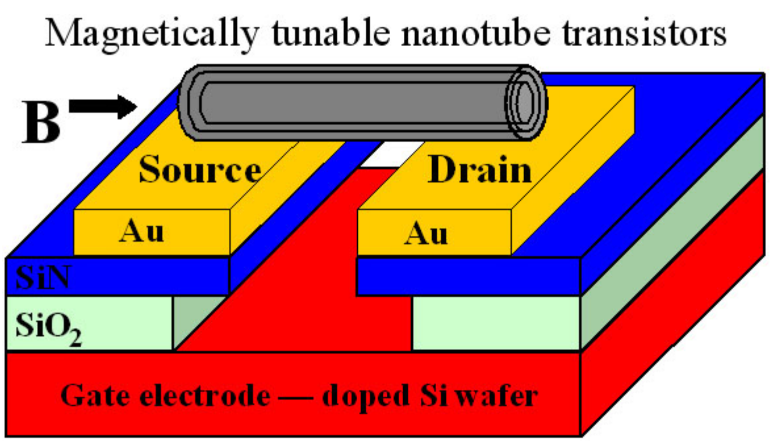
Magnetic Field Converts Carbon Nanotubes From Metal To Semiconductor And Back

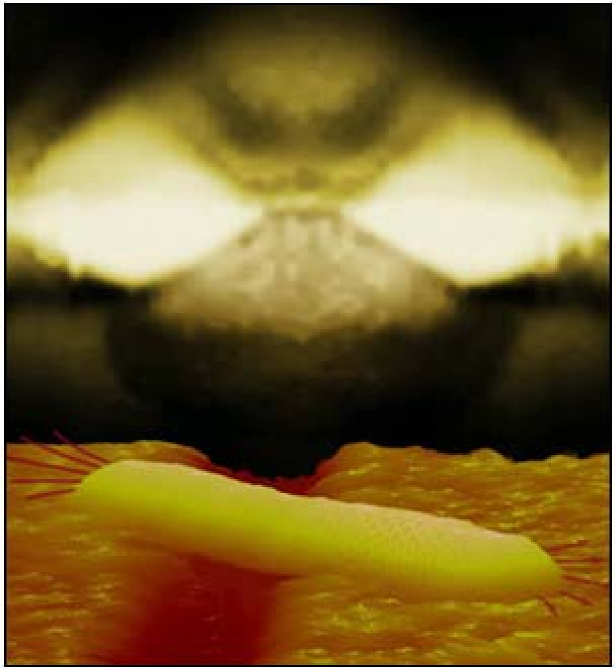
A. Bezryadin, University of Illinois at Urbana-Champaign, DMR-0134770

Experiments carried out in the PI's group demonstrate that a metallic carbon nanotube can be made into a semiconductor and vice versa when a magnetic field is applied along the tube. The magnetic field is able to open and close the gap in the electronic spectrum. Such periodic modulation of the electronic spectrum was know to exist in cylindrical superconductors, and now it is demonstrated in carbon nanotubes.

U. Coskun et al., Science **304**, 1132 (2004)



Single electron tunneling (SET) transistor built on a single carbon nanotube molecule. The operation of the device can be controlled by applying an external magnetic field (B).



Bottom: A carbon nanotube (yellow) positioned over two electrodes (gold), which are used to inject electrons, one-by-one, into the nanotube. The red arrows indicate the magnetic field lines threaded through the tube.
Top: This face-like image represents an experimentally measured conductance "map" of the nanotube transistor, plotted versus magnetic field (horizontal axis) and the bias voltage (vertical axis).

Carbon nanotubes are cylindrical molecules built exclusively from carbon atoms. The diameter of these molecules can be as small as 1 nm. In this work we use larger diameter molecules (about 30 nm). This large diameter allows us to see a new phenomenon: It turns out that carbon nanotubes can be switched from behaving like a semiconductor to behaving like a metal and back again simply by applying a magnetic field along the axis of the molecule. Such effect is in agreement with earlier theoretical predictions following from the most fundamental properties of quantum particles (i.e. electrons sitting on the tube in this example) to change their wave behavior in response to magnetic field. This fining allows us to construct a magnetically tunable transistor operating on single electrons. The active part of the transistor is the carbon nanotube itself, and the transistor can be opened or closed by changing the electric potential of the nanotube. In addition to electronic properties, the mechanical and chemical properties of carbon nanotubes can also depend upon whether the tube is metallic or semiconducting. Thus a possibility arises to control these properties by a magnetic field. This work was published in the May 21, 2004 issue of Science.

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Education and Training:

Two graduate students (Ulas Coskun and Tzu-Chieh Wei) contributed to this work, which involves the fabrication of nanostructures in a clean room environment. Such skills should be extremely valuable for future research and development in the electronics industry. The students also learned the general principles of computer-based computation of the electronic characteristics of nanostructures. The results of this research were disseminated to a general audience by a range of media outlets, including *New Scientist*, *Photonics.com*, *PhysicsWeb.org*, *Innovations-report.com*, and *Semiconductor-International*.

Societal Impact:

Computers and their building blocks, transistors, are extremely important in modern society. One of the key tasks for nanotechnology is to make transistors smaller and faster. So-called single-electron transistors can be made based on carbon nanotubes. We show that the energy characteristics of such transistors can be changed by applying a magnetic field. Thus metallic tubes can be made semiconducting and vice versa. In addition to its electronic properties, the mechanical and chemical properties of a nanotube depend on whether the tube is metallic or semiconducting. These properties might also be controlled by a magnetic field.